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(54) METHOD FOR IMPROVING OPTICAL MEASUREMENT OF GAS CONCENTRATION

VERFAHREN ZUR VERBESSERUNG DER OPTISCHEN GASKONZENTRATIONSMESSUNG

PROCEDE POUR AMELIORER LA MESURE OPTIQUE DE LA CONCENTRATION GAZEUSE

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EP 1 789 773 B1

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Description

[0001] The invention relates to a method according to the preamble of claim 1 for improving optical measurement of gas concentration.

[0002] In US 5 527 031 is described an optical measurement method where a reference gas cell is used for the calibration and locking of the device on an oxygen absorption line. This method is rather complicated and is susceptible to changes in the measurement environment.

[0003] WO 87/07018 describes a calibration method in connection with a oxygen concentration measurement device. In this method the wavelength of the emitting laser is scanned through a range of wavelengths that includes the absorption line.

[0004] US 6 269 110 describes a calibration method for tunable ArF-excimer laser. In this solution the laser has a discharge chamber where a molecular species is introduced for calibration purposes.

[0005] US 6 107 631 describes a self-calibration approach for tunable laser spectral absorption sensors. In this solution stored calibration information is used with current sensor reading information for calibration purposes.

[0006] WO 99/46578 A1 describes an on-line self-calibrating system using one single absorption line.

[0007] EP0 417 884 describes a two-point calibration method for a gas analyzer.

[0008] It is an object of the present invention to overcome the drawbacks of the above-described techniques and to provide an entirely novel type of method for measuring improving optical measurement of gas concentration.

[0009] The goal of the invention is accomplished by varying the center wavelength of the light such that the center wavelength is adapted to coincide with at least two absorption maxima (peak) with different absorption properties of the gas to be measured, and correspondingly the attenuation of the other absorption maxima is measured as a function of the center wavelength of the light.

[0010] More specifically, the method according to the invention is characterized by what is stated in the characterizing part of claim 1.

[0011] The invention offers significant benefits over conventional techniques.

[0012] The implantation of the invention is relatively simple.

[0013] The invention offers an effective two-point calibration in a single gas. Operating the TDL (Tunable Diode Laser) transmitter at a secondary absorption line (e.g. of lower strength) effectively simulates measurement of a lower concentration of oxygen. Due to the precise ratio of the strengths of any two absorption lines, at a given temperature and pressure, is a fundamental property of the oxygen absorption spectrum, and is a physical constant, the calibration is based on absolute accuracy.

This fact offers the possibility to perform ratiometric measurements, using the ideal relationship between the strengths of two absorption lines as a reference, if the absolute absorption at only one line is known. In addition, the position (wavelength) of each individual line in the oxygen absorption spectrum is a physical constant. Knowledge of the position and separation of the lines in the spectrum may therefore be used to determine measurement parameters differentially, if a transmitter is operated at two or more lines. Thus, alternate operation at two or more lines yields significant additional measurement information, which is unavailable if only one absorption line is utilized.

[0014] Therefore, only one calibration gas is required to perform both offset and gain correction. This reduces calibration gas costs for the end-user, compared to a standard two-point calibration using two gases. In addition, the technique offers a more reliable single-gas calibration than a standard one-point field calibration. In certain field-calibration cases, this effective two-point calibration may be performed with an acceptable level of accuracy in ambient air.

[0015] This effective two-point calibration is applicable to both wall- and process-mounted type transmitters. Indeed, in production it may be possible to calibrate the wall-mounted transmitters in the station intended for in-situ process-mounted transmitters, despite the differences in the operational behaviour of the internal series reference path.

[0016] The invention offers self-diagnostic functions. Two-line operation offers the possibility to implement several valuable in-service self-diagnostic functions. These include: oxygen measurement accuracy verification; tunable laser wavelength current-tuning coefficient monitoring; absorption line operating point confirmation. These self-diagnostic functions are of particular benefit in monitoring long-term changes in laser characteristics, and cannot be implemented if only one absorption line is used. The importance of such self-diagnostic capabilities should be emphasised, given the safety-critical nature of many O₂ measuring applications.

[0017] The invention offers also self-adjustment. Operation at two absorption lines enables the transmitter to detect if the VCSEL current-tuning coefficient has changed over time. The laser's current modulation amplitude may then be adjusted, allowing the existing calibration coefficients to be applied more accurately to the aged laser characteristics.

[0018] There also exists the possibility for in-service correction of the measurement linearity, if the drift mechanism is predictable. Clearly, such a self-adjustment system would require rigorous long-term testing.

[0019] The two-line technique is mathematically simple. No complex algorithms or models are required. The additional data-processing requirements are minimal.

[0020] The invention requires no extra hardware compared with single wavelength absorption measurements.

[0021] The method has a fast operation. Due to the

nature of current-controlled wavelength tuning, the two-line technique is very rapid. Interruption to the measurement reading is negligible.

[0022] In the following the invention is described in greater detail with the help of exemplifying embodiments illustrated in the appended drawings in which:

Figure 1 shows a block diagram of a measuring system suitable for the method in accordance with the invention.

Figure 2 is a graph illustrating O₂ absorption spectrum where absorption line pairs with a primary line having more than 60% of normalized absorption are shown in bold.

Figure 3 is a graph illustrating an example of O₂ absorption lines covered by the linear operating range of a typical VCSEL, implementable according to the invention.

Figure 4 is a graph illustrating measured corresponding O₂ signal amplitudes and linear tuning range obtainable according to the invention.

Figure 5 is a graph illustrating first measured O₂ readings from a two-line recalibration test according to the invention.

Figure 6 is a graph illustrating second measured O₂ readings from a two-line recalibration test according to the invention.

[0023] Figure 1 shows a typical measurement system for oxygen concentration measurement. The system comprises a narrow-band light source 1, which could be e.g. Vertical Cavity Surface Emitting Laser (later VCSEL). The wavelength of this type of laser is typically controlled by current by an adjustable current source 2. The light emitted by the laser 1 is directed to a gas-permeable measurement chamber 3 and the attenuation caused by the gas in the chamber 3 is detected by a detector 4.

[0024] In other words in the measurement narrow-band light is directed to the gas to be measured and the attenuation of the light in the gas is measured. The center wavelength of the light source 1 is modulated by the current source 2 around or over a first predetermined absorption maximum (absorption line) of the measured gas and aside of it and the attenuation of the light in the gas 3 as a function of the center wavelength of the light is measured and on the basis of this procedure the gas concentration is determined.

[0025] According to the invention the center wavelength of the light of the light source 1 is further varied such that the center wavelength is adapted to coincide with at least one other absorption maximum (peak) with different absorption properties of the gas, e.g. oxygen,

to be measured, and correspondingly the attenuation of the other absorption maximum or maxima is measured as a function of the center wavelength of the light.

[0026] The two absorption line technique is described in the following in more detail.

[0027] The description begins with the theory of operation and is followed by the measurement results.

Theory of two-line operation of a TDL oxygen transmitter

[0028] The absorption spectrum of oxygen between 760nm and 767nm is shown in Figure 2. In order to maximise the absorption signal amplitude, as detected by the TDL oxygen transmitter, one of the strongest lines of the spectrum is selected as the primary operating line. As seen in the figure, all the strongest lines are accompanied by an adjacent line that has a significantly weaker absorption strength.

[0029] As an example of an application of two-line measurement, it will be shown that it is possible to perform an effective two-point calibration in a single gas. This may be achieved by measuring the O₂ absorption signals at both a primary and an adjacent line. Ideally, the ratio of the signal amplitudes detected by the transmitter will be the same as the ratio of the absorption strengths of the two lines. Knowing that ratio, and the concentration of the single calibration gas, the required calibration coefficients can be calculated. The average ratio of absorption strengths between the primary and adjacent lines shown in Figure 2 is 0.85. In practice, this means that if the two-line calibration is performed in ambient conditions of 21% O₂, then the method effectively simulates a two-point calibration in concentrations of 21% O₂ and 16% O₂. However, due to the inherently linear absorption of O₂, this technique is able to provide a calibrated measurement that retains sufficient accuracy even when the transmitter is measuring low concentrations of oxygen.

[0030] Of practical benefit is that the adjacent line is positioned well within the current tuning range of a typical VCSEL, when operating at the primary line. Figures 3 and 4 show a measured example of this. The linear tuning range of the VCSEL and measured O₂ signals are shown in figure 4, and the corresponding O₂ absorption lines in figure 3. A relatively small change in current of -0.5 mA is required to tune the laser wavelength between the primary line 10 and the adjacent line 11. A decrease in the measured signal peak-to-peak amplitude can readily be seen, in direct response to the weaker absorption strength of the adjacent line 11.

Test results

[0031] The two-line calibration method was tested with a prototype TDL oxygen transmitter. Test results are shown in Figures 5 and 6. The initial response is shown as graph 20, and illustrates the O₂ measurement typically

obtained from a calibrated transmitter. Ageing of the laser was then simulated by manually changing the current modulation amplitude, which in practice results in a condition where the tuning coefficient of the laser appears to have aged, and decreased by a factor of 30%. The effect of this simulated ageing on the O₂ measurement is shown as graph 22, and represents the response which may be obtained from a transmitter exhibiting measurement drift. In this case, a significant error is seen at the 20% O₂ region, whereas the measurement at zero has not changed. The "aged" transmitter was recalibrated with the two-line method in a single gas, meaning in practice that both the offset and gain factors are resolved. The recalibration result is shown as graph 21. It can be seen that the calibration was successful.

[0032] In this instance, since the simulated tuning coefficient ageing is a phenomenon which affects only the gain of the measurement, the zero reading of the "aged" transmitter is still accurate prior to recalibration. However, it should be emphasised that the two-line recalibration recalculates both the offset and the gain factors of the measurement. The method is therefore capable of recalibrating a transmitter with simultaneous gain and offset errors by using only single gas.

Alternative embodiments:

[0033] The system performance may be improved further by defining during calibration procedure the light source 1 control signals, which are required to vary the wavelength to the said first absorption maximum 10 and said other absorption maxima 11, and by using the defined properties of the light source control signals and/or the attenuation information of other absorption maxima for calculations improving the quality of the gas concentration measurement.

[0034] According to the other embodiments of the invention the following additional features may be used:

The narrow-band light is advantageously essentially monochromatic.

[0035] The light source 1 is advantageously an adjustable diode laser or quantum cascade laser.

[0036] The measured properties of the other absorption maxima 11 are in one preferred embodiment used for adjustment of the gas concentration indicated by the measurement device.

[0037] The measured properties of the other absorption maxima 11 are in another preferred embodiment used for gas temperature measurement and consequent temperature correction of the indication of the measurement device.

[0038] The measured properties of the other absorption maxima 11 are in another preferred embodiment are used for self-diagnostic checking of the device.

[0039] The measured properties of the other absorption maxima 11 are in another preferred embodiment

used for determining the wavelength tuning coefficients of the diode laser 1.

[0040] The measured properties of the other absorption maxima 11 are in another preferred embodiment used for determining or verifying the center wavelength of the light emitted by the light source 1.

[0041] The measured properties of the other absorption maxima 11 are in another preferred embodiment are used for determining other properties of the light source 1.

[0042] It is typical for the invention that at least one of the other absorption maxima 11 of the gas is adjacent to the first absorption maximum 10.

Claims

1. A method for two-point calibration of a gas concentration measurement system, the method comprising steps for

- directing narrow-band light to the gas to be measured and measuring the attenuation of the light in the gas,
- modulating the center wavelength of the light source around or over a first predetermined absorption maximum (10) of an absorption line of the measured gas and aside of it,
- measuring the attenuation of the light in the gas as a function of the center wavelength of the light,
- the center wavelength of the light is varied such that the center wavelength is adapted to coincide with a second absorption maximum (11) of a second absorption line with different absorption properties of the gas to be measured, and
- correspondingly the attenuation of the second absorption maximum (11) is measured as a function of the center wavelength of the light,
- detecting a ratio of signal amplitudes corresponding to the ratio of the two absorption maxima (10 and 11),
- calculating calibration coefficients from the detected ratio and a known ratio of absorption strengths of the absorption lines and the known concentration of a calibration gas.

2. A method according to claim 1, **characterized in that** the narrow band light is essentially monochromatic.

3. A method according to any previous claims, **characterized in that** light is obtained from an adjustable diode laser or quantum cascade laser (1).

4. A method according to any previous claim, **characterized in that** the two-line operation is used for self-diagnostic checking of the system.

5. A method according to any previous claim, **characterized in that** the two-line operation is used for determining the wavelength tuning coefficients of the diode laser.
6. A method according to any previous claim, **characterized in that** the two-line operation is used for determining or verifying the center wavelength of the light emitted by the light source.
7. A method according to any previous claim, **characterized in that** the second absorption maxima (11) of the gas is adjacent to the first absorption maximum (10).

Patentansprüche

1. Verfahren zur Zweipunktkalibrierung eines Gaskonzentrationsmesssystems, wobei das Verfahren die Schritte umfasst:
 - Leiten von schmalbandigem Licht zu dem zu messenden Gas und Messen der Dämpfung des Lichts in dem Gas,
 - Modulieren der Mittenwellenlänge der Lichtquelle um oder über ein erstes vorbestimmtes Absorptionsmaximum (10) einer Absorptionslinie des Messgases und seitlich davon,
 - Messen der Dämpfung des Lichts in dem Gas in Abhängigkeit von der Mittenwellenlänge des Lichts,
 - die Mittenwellenlänge des Lichtes wird derart verändert, daß die Mittenwellenlänge mit einem zweiten Absorptionsmaximum (11) einer zweiten Absorptionslinie mit anderen Absorptionseigenschaften des zu messenden Gases übereinstimmt und,
 - dementsprechend die Dämpfung des zweiten Absorptionsmaximums (11) als eine Funktion der Mittenwellenlänge des Lichtes gemessen wird,
 - Erfassen eines Verhältnisses der Signalamplituden entsprechend dem Verhältnis der beiden Absorptionsmaxima (10 und 11),
 - Berechnen von Kalibrierkoeffizienten aus dem erfassten Verhältnis und einem bekannten Verhältnis der Absorptionsstärken der Absorptionslinien und der bekannten Konzentration eines Kalibriergases.
2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** das schmalbandige Licht im Wesentlichen monochromatisch ist.
3. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** Licht aus einem einstellbaren Diodenlaser oder Quantenkaskadenlaser (1) gewonnen wird.

denlaser (1) gewonnen wird.

4. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der Zweipunktbetrieb zur selbstdiagnostischen Überprüfung des Systems verwendet wird.
5. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der Zweipunktbetrieb zur Bestimmung der Wellenlängenabstimmungskoeffizienten des Diodenlasers verwendet wird.
6. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der Zweipunktbetrieb zum Bestimmen oder Verifizieren der Mittenwellenlänge des von der Lichtquelle emittierten Lichts verwendet wird.
7. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** das zweite Absorptionsmaximum (11) des Gases dem ersten Absorptionsmaximum (10) benachbart sind.

Revendications

1. Procédé pour l'étalonnage en deux points d'un système de mesure de la concentration en gaz, le procédé comprenant les étapes suivantes:
 - diriger la lumière à bande étroite vers le gaz à mesurer et mesurer l'atténuation de la lumière dans le gaz,
 - moduler de la longueur d'onde centrale de la source lumineuse autour ou au-dessus d'un premier maximum d'absorption prédéterminé (10) d'une ligne d'absorption du gaz mesuré et en dehors de celui-ci,
 - mesurer de l'atténuation de la lumière dans le gaz en fonction de la longueur d'onde centrale de la lumière,
 - on fait varier la longueur d'onde centrale de la lumière de telle sorte que la longueur d'onde centrale soit adaptée pour coïncider avec un second maximum d'absorption (11) d'une seconde ligne d'absorption avec des propriétés d'absorption différentes du gaz à mesurer,
 - en conséquence, l'atténuation du second maximum d'absorption (11) est mesurée en fonction de la longueur d'onde centrale de la lumière,
 - détecter un rapport d'amplitudes de signal correspondant au rapport des deux maxima d'absorption (10 et 11),
 - calculer des coefficients d'étalonnage à partir du rapport détecté et un rapport connu des puissances d'absorption des lignes d'absorption et

de la concentration connue d'un gaz d'étalonnage.

2. Procédé selon la revendication 1, **caractérisé en ce que** la lumière à bande étroite est essentiellement monochromatique. 5
3. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** la lumière est obtenue à partir d'un laser à diode réglable ou laser à cascade quantique (1). 10
4. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** l'opération à deux lignes est utilisée pour la vérification autodiagnostique du système. 15
5. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** l'opération à deux lignes est utilisée pour déterminer les coefficients d'étalonnage de longueur d'onde du laser à diode. 20
6. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** l'opération à deux lignes est utilisée pour déterminer ou vérifier la longueur d'onde centrale de la lumière émise par la source lumineuse. 25
7. Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** la deuxième maximum d'absorption (11) du gaz est adjacents au premier maximum d'absorption (10). 30

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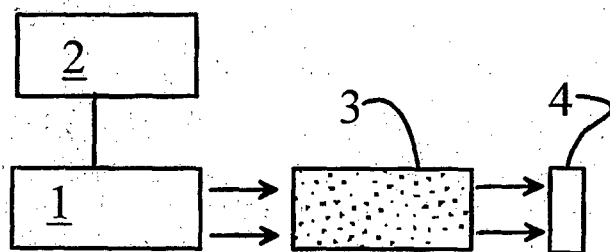


Fig. 1

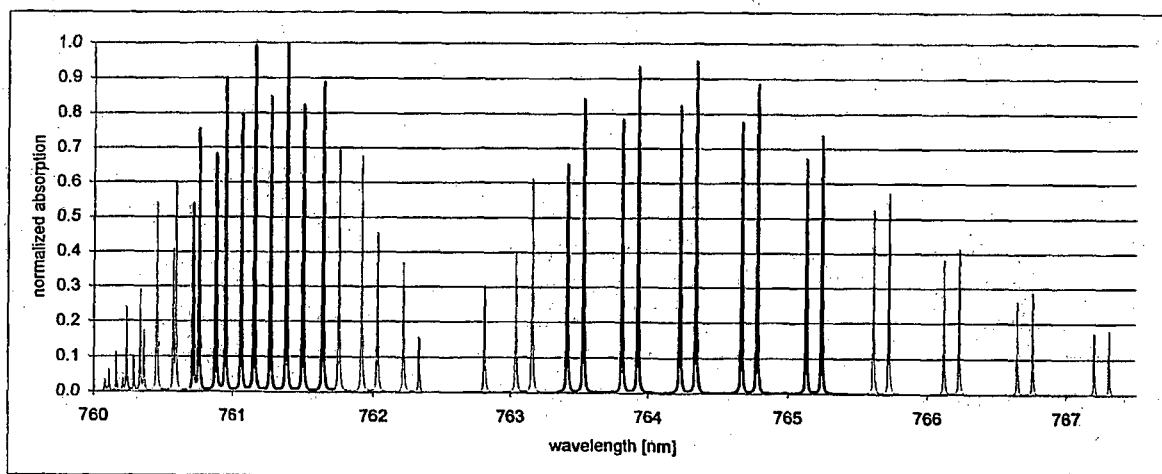


Fig. 2

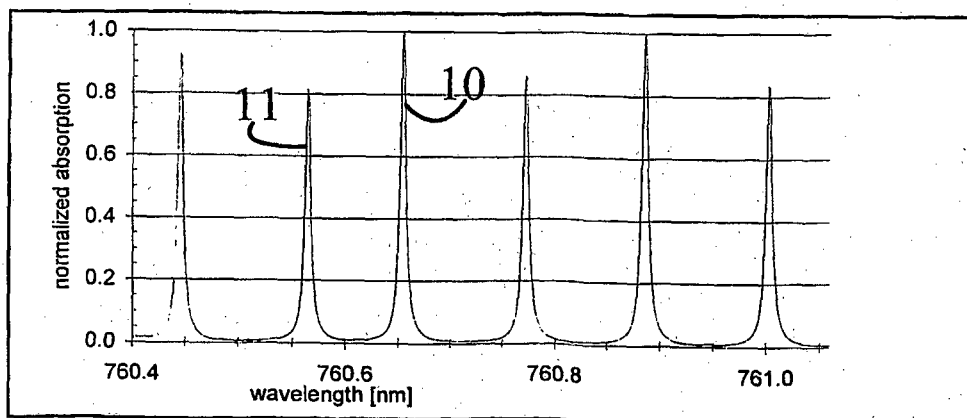


Fig. 3

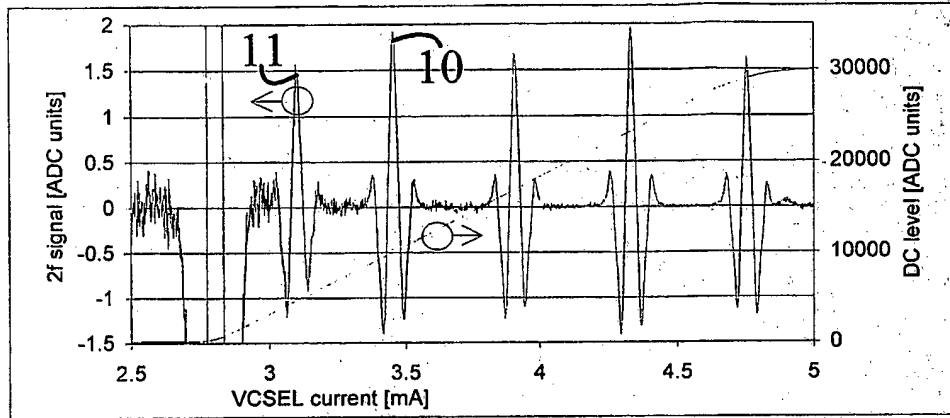


Fig. 4

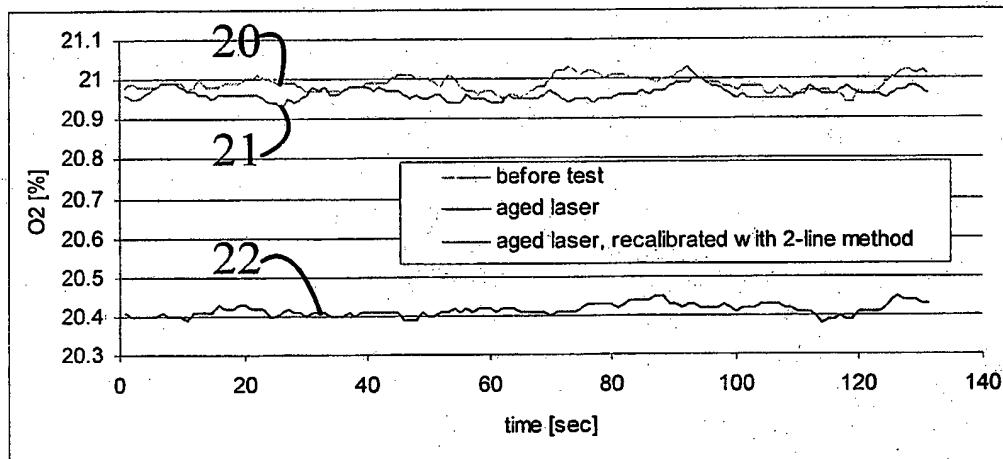


Fig. 5

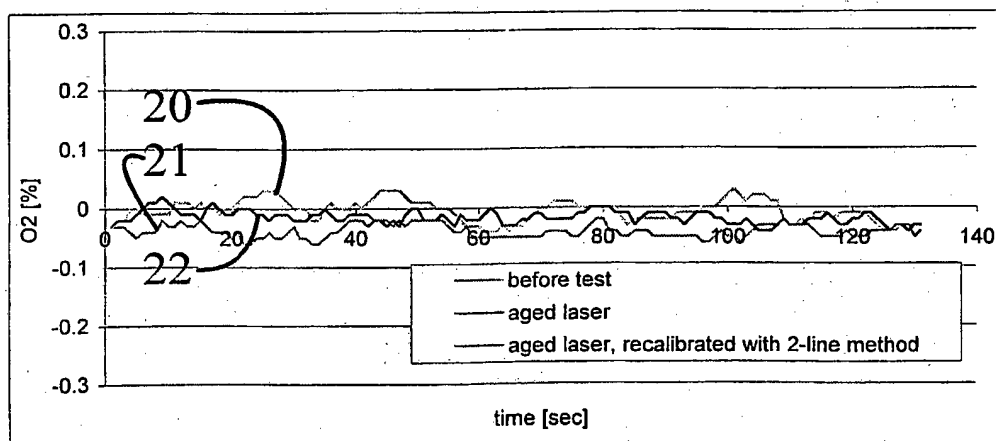


Fig. 6

REFERENCES CITED IN THE DESCRIPTION

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